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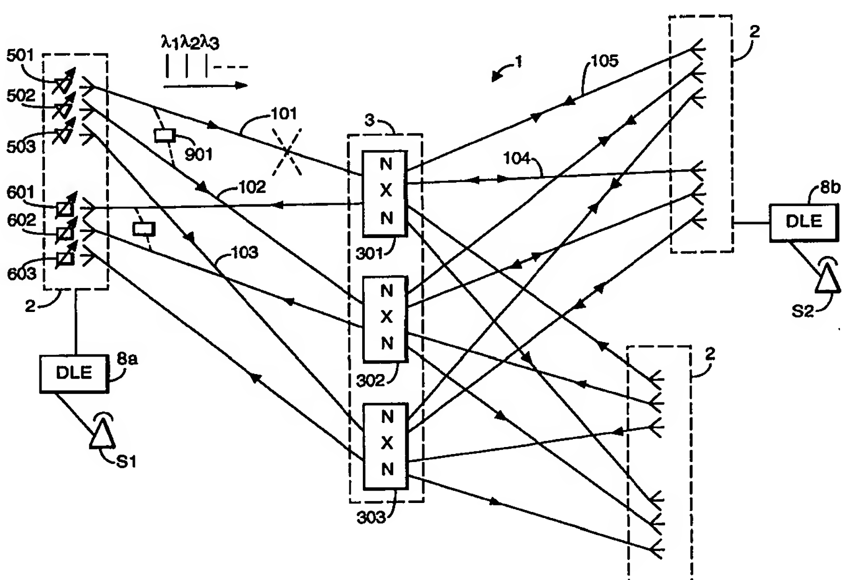

(57) Abstract

A communications system includes an optical network which has a star topology. A number of nodes are connected to the periphery of the network. A number of routers are located at the hub of the network, and route traffic between different nodes depending on the wavelength of received optical signals. Each of the routers is connected in parallel to the different nodes and has a capacity which is less than that of the network as a whole. The total capacity of the routers is greater than that of the network as a whole. Switches may be provided to select alternative routes via the network and the routers in the event of a component failure. The system is suitable for use in a telecommunications core network.

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COMMUNICATIONS SYSTEM WITH STAR TOPOLOGY

The present invention relates to a communications system which employs a network which has a star topology, and particularly, but not exclusively, to networks employing wavelength division multiplexing (WDM).

WDM has attracted considerable interest as a technology which potentially makes it possible to utilise fully and flexibly the bandwidth available on optical networks. Its use has been proposed, for example, in the core network which interconnects trunk switches in a national telecommunications network. A variety of different network structures and switching techniques are possible for implementing a WDM network. These include a star network which may, for example, have connections from N nodes converging on a single NxN WDM router at the hub. An alternative structure is a WDM add/drop multiplex (ADM) ring in which each node adds and drops wavelength channels to and from other nodes. Further alternatives include a WDM broadcast-and-select ring, and an arbitrary mesh. In selecting an appropriate structure, a number of requirements have to be met. Together with the fundamental need to accommodate a suitable number of channels using a channel spacing which can readily be realised, it is important to minimise the cost of the components making up the network. In particular, for a network which is large enough to cover the country, the total length of the fibres used is a major determinant of cost. Another important consideration is the resilience of the network, that is its ability to continue functioning after the failure of one or more components. Hitherto it has proved difficult to reconcile these two criteria: networks which have sufficient redundancy to withstand component failures have required relatively greater lengths of fibres and larger amounts of other components.

According to a first aspect of the present invention there is provided an optical communications system comprising:

a) a network having a star topology;

b) a plurality of nodes which are located at the periphery of the network, each node including:

a plurality of wavelength division multiplexing terminals, each wavelength division multiplexing terminal being arranged to

communicate optical wavelength division multiplexing signals, via the network, with another terminal in a selected other one of the plurality of nodes; and

c) a plurality of routers at the hub of the network, each one of the routers comprising a wavelength division multiplexer having a capacity which is less than the capacity of the network as a whole, and the routers in total having a capacity which is greater than that of the network as a whole, and each of the routers being connected in parallel to a plurality of the said nodes.

In the context of the present specification, the term "WDM terminal" is used to denote a device which terminates a WDM channel, and will typically comprise an electro-optical transmitter or receiver. It includes, but is by no means limited to, equipment at the very end of a communications link, for example at customer premises. In the example described in the detailed embodiment below, the "terminals" are located at a trunk switch which concentrates and distributes traffic via access networks which may include both optical and electrical access networks.

The present invention provides a network which has a simple regular network structure, and which needs reduced fibre lengths by comparison, for example, with WDM rings, but which at the same time provides greatly enhanced resilience by comparison with conventional star networks and WDM rings. This is achieved by using in parallel, at the hub of the network, a number of routers, each one of which is undersized with respect to the total network capacity. That is to say, if the network comprises N nodes, then each router has the capacity to handle only a fraction of the capacity of one node on each of its N inputs. At the same time, the total capacity integrated over all of the different routers is greater than the network capacity. This provides the network with the flexibility to implement alternative routing of traffic in the event of the failure of one or more components. These advantages are not limited to WDM networks, but may also be realised in the context, for example, of an optical network carrying time-division multiplexed SDH (synchronous digital hierarchy) traffic.

According to a second aspect of the present invention, there is provided an optical communications system comprising:

a) a network having a star topology;

b) a plurality of nodes which are located at the periphery of the network, and which are arranged to communicate optical signals with other nodes via the hub of the network ; and

c) a plurality of routers connected to the hub of the network, each one of the routers having a capacity which is less than the capacity of the network as a whole, and the routers in total having a capacity which is greater than that of the network as a whole, and each of the routers being connected in parallel to a plurality of the said nodes.

Preferably the system further comprises an optical switch which is connected to the network, and which is operable to select alternative paths for traffic between the node and another node. In this case preferably the system also includes a controller which is connected to the optical switch and which is arranged automatically to select one of the alternative paths in response to the detection of a fault condition in another of the alternative paths. Such an arrangement may be used, for example, to bypass one of the routers in the event of a failure at that router, or to bypass a failed fibre.

Preferably the plurality of routers include a working router which is arranged to carry working traffic only and a standby router which is arranged to carry protection traffic only. Preferably different ones of the said plurality of routers are located at different sites. The allocation of a router to function as a working router or as a standby router need not be fixed. Rather, a router may be functioning as a working router at one time, and at another time the network may be configured so that that same router functions as a standby router.

It is found that the resilience and cost efficiency of this network is further maximised if routers are allocated either to working traffic or to standby traffic. Standby traffic is traffic which is diverted from its usual working path in the event of a component failure. Locating different routers at different sites further protects the network from vulnerability to localised damage.

Preferably the network further comprises peripheral transmission paths directly connecting different ones of the plurality of nodes.

The resilience and efficiency of the system is further enhanced by adding to the basic star network peripheral connections which pass directly between

nodes. This makes it possible to ensure that the capacity on the main connections between the nodes and the hub is fully used, and also provides further options for the diversion of standby traffic in response to network or router failures.

According to a third aspect of the present invention, there is provided a method of operating an optical communications system comprising a network having a star topology, a plurality of nodes located at the periphery of the network, and a plurality of routers connected to the hub of the network, the method comprising:

a) at the nodes, modulating signals onto different WDM channels carried by optical signals at different respective wavelengths;

b) outputting some optical signals from a node onto one branch of the network which is connected to one of the plurality of routers;

c) outputting other optical signals from the said node onto another branch of the network which is connected to another one of the plurality of the routers; and

d) routing WDM channels received by the plurality of routers to different destination nodes depending on the wavelength of a respective channel.

According to a fourth aspect of the present invention, there is provided a method of operating an optical communications system comprising a network having a star topology, a plurality of nodes located at the periphery of the network, and a plurality of routers connected to the hub of the network, the method comprising:

a) at the nodes, outputting optical signals directed to different destination nodes;

b) outputting some of the optical signals from a node onto one branch of the network which is connected to one of the plurality of routers;

c) outputting others of the optical signals from the said node onto another branch of the network which is connected to another one of the plurality of the routers; and

d) at the hub routing signals received at the plurality of routers to different destination nodes .

Systems and methods embodying the present invention will now be described in further detail, by way of example only, with reference to the accompanying drawings, in which:

Figure 1 is a schematic of a prior art communications system employing a star network:

Figure 2 is a schematic of a network embodying the present invention;

Figure 3 is a diagram showing in detail an optical switch connected in the network of Figure 2;

Figure 4 is a diagram showing a multiplexer/demultiplexer suitable for use in the network of Figure 3;

Figure 5 is a schematic of an alternative multiplexer/demultiplexer structure;

Figure 6 is a schematic showing a second example of a network embodying the present invention;

Figure 7 shows the switching paths at one of the switch nodes of Figure 6;

Figure 8 is a circuit diagram for an experimental implementation of the system of Figure 7; and

Figure 9 is a schematic showing a third example of a network embodying the invention;

Figure 10 is a schematic showing a fourth example of a network embodying the invention;

Figure 11 is a schematic showing an alternative structure for a router;

Figure 12 shows the distribution of channels from one node between working routers;

Figures 13a and 13b show examples of routers implementing the distibution scheme of Figure 12.

As shown in Figure 1, a conventional communications system includes an optical fibre network 1 which has a star topology. A number of nodes 2 are positioned at different locations at the periphery of the network. The nodes 2 are connected via the optical fibre network 1 to a router 3 which is located at the hub of the network. In this example, the router is an NxN passive wavelength division multiplexing router. It interconnects N inputs and N outputs, where N is chosen to be equal to the number of nodes in the network. In the branches of the optical fibre network 1, optical amplifiers 4a, 4b are included so that the network operates transparently, that is without opto-electronic conversion and regeneration. Each of

the nodes 2 includes a number of transmitter terminals 5 and receiver terminals 6. The wavelengths of operation of the transmitters and receivers are variable.

In use, when one of the nodes is to route traffic to another one of the nodes, then a transmitter terminal at the originating node is tuned to a wavelength channel which is selected in dependence upon the intended destination. The signal is then output in the optical domain by the selected terminal, combined with other wavelength channels from other transmitter terminals and travels along the outgoing fibre in the respective branch of the optical fibre network 1. At the hub of the network, the fibre from the originating node is connected to one of the N input ports of the router 3. The router directs the signal internally to one of the N output ports. Which output port is used depends on the wavelength of the signal. The signal then passes over the optical fibre network to the destination node. The destination node separates each wavelength channel, eg by means of a wavelength demultiplexer or a splitter and set of tunable filters. Completely non-blocking operation can be obtained, for any traffic matrix between nodes, by employing wavelength conversion between dummy ports around the router.

In this conventional communications system, and also in systems embodying the invention, the variable transmitters and receivers may be replaced by sets of fixed wavelength transmitters and receivers, with different transmitters and receivers operating at different wavelengths. Such a system still functions generally as described above, but with a reduced degree of flexibility. Where fixed wavelength operation is used, then wavelength multiplexers may be used to join, e.g., groups of transmitter terminals to an outgoing optical fibre.

Figure 2 shows a communications system embodying the present invention. As in the network of Figure 1, an optical fibre network 1 with a star topology links nodes 2 to the hub 3 of the network. Now however, instead of a single NxN router, the hub comprises a number of NxN routers, each of which is still connected to all of the N nodes but now receives traffic from only a subset of the terminals within each node. The total capacity of all of the routers, in terms of the number of different channels which can be handled by the routers, is greater than the total capacity of the N nodes. The Figure shows how, at each of the nodes, the transmitter terminals 5 and receiver terminals 6 are divided into groups. By way of illustration, in the node which is referenced 2a a first group of transmitter terminals 501 have their outputs coupled by a non-wavelength

selective fibre couplers 7 onto the outgoing optical fibre which is referenced 101. That optical fibre is connected to an input in the first one of the routers, which router is referenced 301. A second group of transmitter terminals 502 are coupled via a second optical fibre 102 to a second router 302, and the third group of transmitter terminals 503 are connected via a third optical fibre 103 to a third router 302. In a similar manner, receiver terminal groups 601, 602, 603 are connected to outputs of routers 301, 302 and 303 respectively. Optical switches 9 are connected between the different branches of the network. As described in further detail below, the switches may be operated to bypass one or more of the fibre paths and/or one or more of the routers in the event of a component failure.

In relation to the topology of the network, all of the NxN routers are located at the hub of the network. However, advantageously different physical locations are used for the different routers. The routers may be divided between several sites, or each router may be sited individually. In the UK core network, for example, the different sites may all be located within a 10km radius of the geographical centre of the network. The use of different sites further enhances the resilience of the system by reducing the effects on the system of, e.g., accidental damage or fire at a single site.

In this example, the communications system forms the core network of a national telecommunications network. Each node is a trunk switch and is connected to a number of digital local exchanges (DLE's) 8a, 8b. The connections between the DLE's 8 and the nodes 2 may include both broadband circuits using, for example, ATM (asynchronous transport mode) and also conventional narrowband circuits for voice telephony. Although for ease of illustration only three nodes are shown, in practice, in the UK core network for example, 23 nodes may be used. Typically, for a system of this size, 12 23x23 routers may be used at the hub of the network.

In use, when a first customer S1 connected to a first DLE 8a makes a call to a second customer S2 connected to a second DLE 8b, then the call is initially set up in a conventional fashion, using network signalling messages to establish a circuit which extends across the core network from the first DLE 8a to the second DLE 8b. The node 2a, which is functioning as a trunk switch, receives signals from the customer S1 via the DLE 8a in the electrical domain. The customer signal

is switched electrically to one of the transmitter terminals 501, which it then modulates . For example, in this instance, one of the terminals 501 which are connected to the first optical fibre 101 is selected. The wavelength of operation of the selected terminal is set by a traffic or network management system (automatically, manually or by design), depending on the intended destination nodes. In the case of a 23 node network, 45 different wavelengths within the erbium window, with channel spacing of 0.8nm, may be used across the network. Each group of terminals connected to a single branch of the network uses a respective subset of 23 of the 45 possible wavelengths, providing one wavelength channel for each of the other nodes. In this example, the second wavelength channel λ_2 is selected for the transmitter terminal 501. An optical carrier at that wavelength modulated with the signal from the customer S1 is output on fibre 101 to router 301. The router 301 routes signals received at the relevant input port at wavelength λ_2 to the output port which is connected via optical fibre 104 to node 2b. At node 2b a receiver terminal which is tuned to the λ_2 channel converts the signal back to the electrical domain. The signal is relayed via DLE 8b to the destination customer S2. Similarly, a connection is established in the reverse direction via fibre 105, router 301, and fibre 106. In this way a duplex circuit is provided between the two customers. Within the core network, the circuit is part of a multiplex of traffic from different customers which is carried between the nodes.

Suitable devices for implementing the transmitter terminals 501 include Distributed Bragg Reflector (DBR) lasers and grating-assisted vertical coupler semiconductor lasers. Such devices are tuneable over a 35nm range within the erbium window. Examples of such devices are disclosed in the present applicant's copending International Patent Application no. PCT/GB 96/02424 (Applicant's Reference A25036). Alternatively, the tuneable source may be in the form of an amplifier and modulator such as those described in D.J. Pratt et al., "Tunable Source Options for Race-2070 Project (MUNDI)" Cost 240 workshop, Marcoussis, France 25th October 1993. This design uses a mechanically tuneable optical filter and a semiconductor amplifier/modulator to select a required wavelength channel from a comb of reference wavelengths which are broadcast form a central location to a large number of terminals.

For the receiver terminals, a tuneable filter is used in combination with a photodiode. The filter may be a mechanically tuned Fabry Perot cavity, an angled interference filter, or a tuneable grating filter.

As so far described, the example assumes that all the network components are functioning normally. However, an important feature of the network is its ability to adapt to component failures. For example, a break might occur in fibre 101 at the point indicated by the cross in dashed lines. In this case optical switch 901 is used to bypass the break, allowing the circuit between the two subscribers to be maintained. Figure 3 shows in detail the manner in which the optical switches are arranged to achieve this. Each of the outgoing optical fibres is tapped within the node at taps t1-t4. The signals from the taps t1-t4 are taken to an optical switching system which comprises a number of 2x1 optical switches, such as those available commercially from JDS Optics, connected in a tree structure as shown. Fault signals may be handled centrally by network management logic, or may be restricted to the element management level for a faster response. An electrical control signal which is generated by network management logic or by element management logic located with the node, is applied to the optical switching system. In this case, where a break has been detected in the first of the output fibres, the switches are set to pass the signal from tap T1, and to block the signals from the other taps. The optical output from the switching system is passed to a WDM demultiplexer. The multiplexer splits up the channels which were originally present on the first output fibre, so that one channel is placed on each of the other fibres. To enable this, the set of wavelength channels output onto each fibre includes a spare channel which is normally left empty. This spare channel is marked by a dashed line in the Figure. Each of the outputs from the demultiplexer is arranged to carry a signal at a wavelength corresponding to the spare channel on the respective output fibre.

The arrangement illustrated in Figure 3 enables the network to continue functioning in the event of a single failure at a router or in a fibre. To provide the capacity to withstand a number n of simultaneous failures, the illustrated switching system is replicated n times. Each fibre and router then requires only a small fraction n/(r-n) of additional wavelengths, where r is the number of routers, in order to provide the required degree of resilience.

A star network which is constructed in this way is far more resilient than the equivalent WDM ring. In a ring, multiple fibre breaks spread around the ring cause node-node connections to become more and more localised within sections of the ring between pairs of breaks. In a multiple-star structure embodying the present invention, by contrast, complete recovery from the effects of multiple breaks or failures is possible. At the same time, the network topology makes possible savings in the lengths of fibre required. Calculations by the inventor indicate that in a network covering the United Kingdom, the length of fibre required is 250,000 km less than other competing topologies.

Figure 4 shows a first example of a router which is suitable for use in the networks described above. It comprises a curved mirror which may be parabolic or spherical, a diffraction grating and a linear array of fibres and partially collimating microlenses. To provide nxn connectivity, the device uses two arrays of n monomode optical fibres. As described in further detail in our copending International Application no. WO95/26592, the contents of which are incorporated herein by reference, each array is formed by locating fibres in grooves etched in a silicon substrate.

When traffic is uniformly distributed across the network, then an entirely passive router such as that shown in Figure 4 is suitable. When however a non-uniform distribution is expected, for example when one of the nodes is expected to send a relatively higher concentration of traffic to a sub-set of the other nodes, then preferably the router is modified to include dummy ports, as shown in Figure 5. As described in our above-cited application, the dummy ports may be used to carry out wavelength conversion for selected incoming signals, so that, in effect, two or more wavelength channels are assigned to a single route across the network.

Figure 6 shows a second example of a network embodying the present invention. An optical fibre network 61 which has a star topology links N switch nodes 62 to the hub 63 of the network. A plurality of NxN routers R are located at the hub. Groups of optical fibres 64, which are termed "spokes", carry traffic between the switch nodes 62 and the routers R. In addition to the spokes, peripheral optical fibre connections 65 are connected around the network and provide direct interconnection of adjacent switch nodes. As will be further described below, the peripheral optical fibre connections provide protection

against path failure in a way which minimises the total fibre quantities required by the network. The enlarged detail in Figure 6 shows optical amplifier chains 66 included in the spokes to provide transparent, that is loss-less, operation. The spoke is terminated at the switch node by tuneable WDM transmitters 67 and receivers 68.

In the present example, path protection is achieved by providing additional "standby" fibres, that is to say fibres which are additional to those fibres, termed the "working" fibres, needed to carry all the channels of the network when the network is functioning normally. The standby fibres may extend along one or more of the working spokes, as shown in Figure 6. In an alternative arrangement, the standby fibres are grouped together in a standby spoke. The standby spoke is then connected to a standby switch which functions only to redirect traffic to/from others of the switch nodes in the event of a path failure. In either arrangement, the network is configured so that the working and standby paths from any switch node to the router is disjoint. In the example of Figure 6, this is achieved by mesh interconnection between the switch nodes and routers. For ease of illustration, connections to and from two only of the spokes are shown.

The working and standby fibre paths may be arranged in the network in different ways depending on the degree of protection against path failure ("path protection") or protection against router failure ("router protection") which is required. If there were just two cable routes leaving a node, then to protect against failure in one route would require the number of optical fibres to be doubled, so that each route carried standby fibres for the other route. Such protection is termed 1:1 fibre protection. However, protection can be achieved at less expense if m of the spokes have standby fibres and the standby fibres are shared between N working spokes to give m:N protection. Possible configurations for the network include: all working traffic from one switch node along one spoke; half along the one spoke and half along an adjacent spoke; one third along the one spoke and one third each along two adjacent spokes. The peripheral optical fibre connections may carry both working traffic and protection traffic: protection traffic is traffic which has been diverted from its usual path in response to a path failure. Additional protection can be achieved if the network has switching flexibility to

allow selection of different standby paths in the event of failure, rather than a single predetermined standby path being associated with a given working path.

By carrying working traffic between nodes on the peripheral optical fibre connections, the network ensures maximum utilisation of the network capacity while tending to minimise the amount of optical fibre required. If the number of wavelength channels from a node is such that one fibre is not fully filled, then only fully-filled fibres are taken directly to the hub from the node. The other wavelength channels are taken via the peripheral optical fibre connections to one or more of the other nodes, and are there combined with other channels to fill a whole fibre to the hub. A second fibre pair in the peripheral optical fibre connections is used to provide conventional bi-directional ring protection against breaks. The ring is used in both directions simultaneously, so that at most a node-node connection only has to go half way around the ring, instead of all the way. When a break occurs in the ring, traffic approaching the break is diverted back along the ring in the opposite direction around the ring, but propagation is still in both directions at any point around the ring the direction of propagation is reversed at nodes adjacent to the break

Another feature of the network is that each and every working node is connected to all the working routers. To enable this, the routers have the same number of ports as the number of nodes N. In implementations where the number of wavelength channels which can be supported by the optical fibres is less than the number of wavelengths employed by the routers, then wavelength conversion is used at the router to map some incoming wavelengths to different wavelength channels.

As described in relation to the first embodiment above, in general a given wavelength channel from one node goes to a particular one of the other nodes. If the capacity required on a connection between a pair of nodes is not an integral multiple of the capacity of a single wavelength channel, then this might lead to under-use of the network capacity. To avoid this, when a given node-node connection requires a capacity, e.g. of 4.5 wavelength channels, the fractional capacity is provided by time-division of one of the wavelength channels. This is implemented, for example, by periodic tuning of a wavelength converter at the router. In this example the port on a wavelength router carrying a 5th wavelength channel is connected to a wavelength converter which is tuned, for half of the

time, to a wavelength which allows the optical signal to pass to the same destination node as the other 4 of the 4.5 wavelength channels. For the other half of the time the wavelength converter is tuned so that the channel is thereby switched by the router so as to divert the signal to another node-node connection where a .5 channel capacity is required. The switching is scheduled with respect to a master clock which is distributed between the nodes. Control logic managing traffic at the node selects an appropriate time slot for transmission of signals which form part of the 4.5 wavelength node-node circuit.

Table 1 shows performance parameters for different path protection strategies which may be implemented on the network of Figure 6. The parameters are the fibre increase factor, which is the relative increase in the quantity of fibre required to implement the protection strategy, the proportion of fibre paths (spokes) in the network which can fail simultaneously, and the ratio of these two parameters. This last parameter is a measure of the increase in fibre quantity (and hence the cost) of each unit of protection. The Table includes examples with one working path from each switch node (in which case the peripheral fibre connections carry standby traffic only) and with two working paths from each switch node (in which case the peripheral fibre connections carry working traffic as well as standby traffic)). In this example N, the number of switch nodes, is 23.

Table 1 shows that a large increase in fibre quantities is necessary to ensure protection against a large proportion of simultaneous fibre path failures, as one would expect. Nevertheless, the concomitant fibre increase/unit of protection is at its lowest at this extreme, indicating that the greater the degree of protection, the more efficiently it can be provided. Although fixed standby paths provide very efficient protection, they result in traffic loss when a large proportion of path failures occurs, which flexible standby paths do not. However, since in practice the probability of e.g. half the fibres in a network failing simultaneously is very low, protection is generally only required against a small proportion of path failures. For example, to possess protection equivalent to a WDM ring, where fibres are duplicated for protection against a single break, the multiple-star network would need only $m=1$ standby path. This single standby path must, however, in this case, use a separate standby spoke. The analysis for Table 1 allows for the worst case where all spoke failures occur in contiguous spokes.

Table 1

Protection Strategy	Fibre Increase Factor, A	Proportion of Path Failures, B	Increase/Unit of Protection, A/B
1 working path, 1:N protection, lexible standby, no traffic loss	1.32	0.043	30.3
1 working path, N/4:N protection, lexible standby, no traffic loss	2.51	0.20	12.5
1 working path, N/3:N protection, lexible standby, no traffic loss	2.90	0.25	11.6
1 working path, N/2:N protection, lexible standby, no traffic loss	3.59	0.33	10.8
1 working path, N:N protection, lexible standby, no traffic loss	5.14	0.50	10.3
2 working paths, 1:2 protection, ixed standby, 25% traffic loss	1.77	0.50	3.5
2 working paths, N:2N protection, lexible standby, no traffic loss	3.59	0.33	10.8

In the preferred implementation adopted here, the network is configured for m:N path protection, with all working fibres taken directly to the hub along N spokes, and additional standby fibres taken along m of the spokes. A further increase in fibre quantities is needed to account for the peripheral fibre connections which carry the protection traffic. The overall increase in fibre quantities for m:N protection is given by:

m:N path protection (non-diverse) fibre increase factor,

$$A = 1 + m/N + m\pi/N$$

m:N path protection (diverse) fibre increase factor,

$$A = 1 + m/N + m2\pi/N$$

and for $m=1$ (allowing 1 spoke failure without loss of traffic)

1:N path protection (diverse) fibre increase factor,

1:N path protection (diverse) fibre increase factor,

$$A = 1 + 1/N + 2\pi/N$$

Figure 7 shows in further detail the switching arrangements at one of the switch nodes when the network of Figure 6 is configured for m:N path protection. Working traffic is carried directly from the switch node to the router R at the hub along one of the spokes S2. If the working path fails, traffic switched either way around the peripheral fibre connections to a node with an available standby fibre path to the router R along a respective spoke S1 or S3. 2x2 optical switches sw in the switch node are configured so that when a node is not making use of standby fibres for its own protection, then protected traffic from other switch nodes received on the peripheral fibre connections passes straight through the switch node. The switching arrangement illustrated in Figure 7 may be elaborated to handle multiple sets of standby fibres in the peripheral connections, and to handle standby fibres, in addition to working fibres, in a respective spoke.

Figure 8 shows an experimental implementation of the arrangement shown schematically in Figure 7. In this implementation the hub contains a 22 x 22 wavelength router, described in further detail below, together with a personal computer which is used to control electromechanical optical switches which are deployed around the wavelength router, to provide path protection switching. The hub is linked via a 75km go and return path to a major switch node, and via 2 separate 200km standby paths. The standby paths traverse nominal major switch nodes, which contain optical amplifiers. The fibre links include attenuators to provide between 25 and 27dB path loss: this corresponds to the extra loss that would be present in a typical installed fibre link. Switch losses in the 2x2 optical switches are between 0.5dB and 3dB, depending on position. Typical amplifier output powers are +14dBm to +17dBm. The optical SNR (signal/noise ratio) at the receiver is typically better than 20dB in a 0.1nm bandwidth. The major switch node contains a 16 wavelength WDM transmitter, covering the range from 1547.74nm, to 1560.55nm, with 100GHz channel spacing. Individual channel wavelengths are optimised for transmission through the router. The WDM transmitter is externally modulated at a bit rate of 2.5Gb/s for the purposes of measurement. The receiver array is represented by the combination of a variable attenuator, mechanically tuneable filter with 0.5nm FWHM bandwidth, and an APD receiver. Typical attenuations well in excess of 20dB are required to reduce the

power from the preceding EDFA to the level required for a 1 in 10^9 error rate at the receiver for both working and standby paths. Thus, a sufficient power budget exists to accommodate a 16-way splitter (approx 13dB) and 16 tuneable receivers incorporated into a fully functioning network.

In this example, a m:N path protection strategy was implemented as follows. To simulate a fibre break, switch S1, on the working path between the hub and the operating major switch node, was operated to open this path. The switch was positioned close to the hub, to maximise the deleterious effects of propagation delay. At the receiver a photoelectric detector D1 is filtered to monitor a wavelength known to originate from this node. This detector then detects the reduction in power caused by the simulated break. The detection of this reduction in power causes a 2x2 optical switch S2 on the transmit side of the node to be thrown.

A time constant of at least 125μs is associated with photodetector D1. This time constant, which corresponds in length to one SDH (Synchronous Digital Hierarchy) frame, acts as a persistence check to ensure that a real break has been detected. In the present implementation an effective time constant of a few ms was used. After S2 has been thrown, the loss of transmit signal, after propagation back to the hub, is detected by another photoelectric detector D2, which is loosely filtered to discriminate against ASE (amplified spontaneous emission) from the EDFA's (erbium doped fibre amplifiers). When this loss is detected, the information is sent as a TTL signal to a small personal computer (PC), which contains a control algorithm to detect the TTL transition and choose an appropriate spare path, based on knowledge of the network condition. The present implementation of this control algorithm can handle up to 8 nodes, and has a response time of 800μs on a 386 PC. Depending on the choice of standby path made by the control algorithm, then the appropriate switches are thrown. For example, for Standby Path 1, switches S4 and S5 are thrown. An additional DFB (distributed feedback) laser, which may operate outside the main band occupied by the WDM channels, is placed at the hub. This additional DFB laser generates a probe signal for use in the path restoration process. This signal propagates down the standby path to the switch node. At the switch node the signal is detected by a photodetector D1. This detector, which ideally has a faster response time, around 10μs, causes switches S9 and S10 at the node to switch, and so brings the standby path into operation.

Finally, after propagating back around the standby path, the presence of the restored signals is detected once again by D2, which informs the controller that the restoration path is intact. Full restoration only occurs when these signals propagate back to the node, down the standby path (representing propagation via the wavelength router to all other nodes in the network).

In the present example, the wavelength multiplexer which is used as the router is a 22x22 port router with a channel spacing of 0.8 nm. It employs a Stimax (TRADEMARK) multiplexer configuration with a double array of N fibres to provide an NxN WDM multiplexer. The Stimax mulitplexer is commercially available from Jobin-Yvon - Spex. The device provides a maximised ratio of channel width to channel spacing using single-mode fibres (typical FWHM of 0.21 nm) and losses are below 4 dB. The router has a polarisation sensitivity of between 0.3dB and 0.8dB, depending on wavelength and path through the router. The range of wavelengths routed from any input 1 to 22 to any output 1 to 22 is given in the following matrix (Table 2). The design minimises wavelength errors between the wavelengths of the ITU frequency standard and the channel centre wavelengths. The maximum residual error is 0.04 nm over the wavelength range 1538-1560 nm when the multiplexer is heated to 28.1°C. The router has half connectors attached to all 44 fibre tails, and is housed within a thermally controlled environment, in order to raise its temperature, and thereby minimise the wavelength errors.

	IN	1	2	..	9	10	11	..	20	22
OUT										
1		1563.73	1562.95						1548.53	1546.94
2		1562.95	1562.15						1547.74	1546.14
:										
9					1550.95		1549.33			
10						1549.33				
11					1549.33	1548.53	1547.74			
:										
19		1549.33	1548.53						1534.14	1532.53
22		1546.94	1546.14						1531.72	1530.13

Table 2: Extract from 22x22 Wavelength Multiplexer Routeing Matrix

Router protection in the network of Figure 6 will now be described. As in the first embodiment, the capacity of each switch node is shared between a number r of routers and each router carries a fraction 1/r of a respective switch node's traffic. However, in the present example, rather than using standby fibres for router protection running directly from switch nodes, or using wavelength channel switching, connections for standby paths for router protection are made to and from working fibres in a region which is closer to the hub than to the switch nodes, but which is far enough away from respective working routers to be unaffected by localised causes of failure (such as fire or other physical damage). The connections to the working fibres may be by way of switches or by splitting/coupling. Optical fibre paths extend from the working fibres to standby routers a distance $xR << R$, where R is the distance of the working fibre path from a switch node to a working routers. In implementations where splitting/combining is employed, then the standby routers themselves switch in fibres from failed routers. In such implementations, if the standby fibres from the splitters/combiners to the standby routers are arranged in a star topology, then the increase in fibre lengths for implementing the router protection strategy is given by a factor of $1 + xn$ (where n is the number of standby routers).

In an alternative and preferred implementation, instead of a star topology being used for the connection between the splitters/combiners and the standby routers, a bus topology is used. As shown in Figure 9, the optical fibre bus runs across the working fibre paths at a distance from the routers such that the maximum path length via the bus to a standby router is xR. Working fibre paths

are joined to the optical fibre bus by splitters/couplers sequentially along the bus. To provide enhanced resilience, duplicate optical fibre buses are used, with each bus taking a different physical route. Using duplicate buses, the additional fibre required for router protection is given by 1 + 2x. If only a single bus is used, then the relevant factor is 1 + x. In this implementation, each standby router requires a number 2N of rx1 optical switches. Each rx1 switch enables a fibre connected to any of r router locations to be switched to one of the n standby router locations. In use, when a working router fails, all the fibres from all the switch nodes connected to that working router can then be switched to one of the n standby router locations.

As a further alternative, instead of connections to the working fibre being by way of fixed splitters/couplers, switching is employed using an r x (r + n) optical switch at the connection to each working fibre (where r is the number of working routers and n is the number of standby routers). Failure at the r x (r + n) switch site may be treated as a path failure, and is then encompassed by the path protection scheme outlined above, using a standby spoke. In this case, the increase in fibre lengths for the router protection scheme is given by a factor 1 + xn/r

In operation, using either of the router protection strategies described above, the router carries out self-diagnostic tests. These include monitoring power levels and the presence of individual wavelength channels on each of the incoming and outgoing optical fibres. When, as a result of these tests, a router failure is detected, then a message is sent to all other routers, both working and standby. Supervisory signals are sent between routers and/or between routers and one or more centralised locations, so that all routers and/or control logic at the centralised location(s) are aware of the status of all routers. In one implementation, supervisory signals are sent over a separate data communication network (DCN). Alternatively the supervisory signals may be sent over the fibre infrastructure described above. Signals are sent sufficiently frequently from each router, or alternatively continuously, so that the disappearance of a supervisory signal is used as a fast indication of router failure, for example within 0.5 msec. When a router fails, a supervisory signal is turned off. This may be done under the control of the router in response to the detection of a failure, or may be direct result of the failure. Control logic, which may be implemented on a control processor at a

centralised location or may be distributed between the router sites, selects a free standby router to take over from the failed router. The time taken for the selection of a standby router in response to a router failure is short, e.g. a few milliseconds. Propagation delays are small since standby routers are at most xR from the working routers, where xR may have a value, e.g., of 10km.

The control of router protection and path protection are interdependent. A node may interpret router failure as a path failure (unless path protection is only implemented if all fibres arriving at a node from all routers along one path fail simultaneously). Before a path protection controller can begin the setting up of a protection path it checks with the router protection controller that router failure is not the cause.

The wavelength routers in the above examples use an NxN wavelength multiplexer, some of whose ports are used as "dummy" ports, containing one or more wavelength converters, which enables the router to become fully non-blocking, when the wavelength converters are used in conjunction with tunable transmitters and receivers at the node locations. The three sets of tunable elements provide a 3-stage switching structure. However, his use of "dummy" ports requires additional ports and wavelength channels than are strictly necessary. An alternative structure is shown in Figure 11. This splits a router into two NxN wavelength multiplexers, with the wavelength converters positioned between them. Now each wavelength multiplexer requires no additional "dummy" ports, which keeps the number of wavelength channels to a minimum, and eases the device fabrication difficulty. The disadvantage of this is that all traffic must now pass through a wavelength converter.

The invention is not limited to implementation using NxN WDM routers. For example, each NxN router in the above examples may be replaced by a full-scale optical cross-connect. Nor is the invention limited to use with WDM technology. Figure 10 shows an implementation using SDH (synchronous digital hierarchy) technology. Where the previous examples use working and standby wavelength routers, whose task is to route individual wavelength channels from a given node to any other node in the network, their place is taken in this example by working and standby SDH cross-connects, whose task is now to route SDH systems from a given node to any other. The granularity of the routed SDH

systems is optional, depending on the traffic matrix between the nodes. For example, the network may carry individual 2 Mbit/s channels, or STM-1 channels, STM-4 channels, STM-16 channels etc. If the traffic matrix is uniform, then ideally the granularity of the channels within a fibre matches the number of nodes to be connected to (ie N-1). For example, if each fibre carries only one STM-16 system (as indicated in the figure), and the SDH cross-connect only has STM-1 switching granularity, then N = 17 nodes is ideal.

Although wavelength routeing is not used in this SDH example, it is still possible for WDM to be employed just for transmission capacity purposes within the fibres between the ATM switch nodes and the SDH cross-connects. For example, each fibre could support 16 STM-16 systems, or even 16 STM-64 systems using 16-channel WDM within the fibre. At the SDH cross-connects the wavelength channels are converted to and from electrical signals.

As in the wavelength-routed use of the multiple-star network, any residual channels from a node that are insufficient to fill a complete fibre from the node to the hub (SDH cross-connects) are transmitted around the perimeter of the network to an adjacent or further node, until they can be multiplexed with other nodes' channels to fill a fibre to the hub. The perimeter is also used for path protection purposes. Although wavelength routeing is not available in this case, the protection channels could still be switched around the perimeter by means of optical switches. Alternatively, the ATM switches themselves may fulfill this purpose. As a further alternative, additional SDH cross-connects or add-drop multiplexers (ADMs) are connected to the ATM switches for this purpose. The residual channels are switched by either the ATM switches or by associated SDH cross-connects or ADMs.

All the topological structures and operational principles described previously, including the protection strategies, apply to this SDH example, albeit with some differences in the details of implementation. The multiple-star network structure employing SDH cross-connects requires less fibre than an SDH ring.

Port-port connections in one or more of the hub SDH cross-connects are time-shared in order to provide the exact node-node capacity, or close to that capacity. Suppose, for example, that each fibre from a node carries an STM-16 system (2.48 Gbit/s), and that an STM-1 channel (155 Mbit/s) is routed by each

SDH cross-connect to every other node (ie N=17 nodes, uniform traffic matrix between nodes). If now the capacity between each node pair is assumed not to be sufficient to fill all STM-1 channels, then one of the STM-1 channels, instead of being dedicated between one input port and one output port of a cross-connect, will have smaller units of capacity, eg 8 Mbit/s (4 off 2Mbit/s), switched to multiple output ports by the cross-connect. Similarly multiple input ports would be multiplexed into one output port for the return path.

As a further alternative, another implementation may use a conventional optical cross-connect as the router in combination with fixed-wavelength WDM at the nodes.

In the implementations using WDM technology the router may include dummy ports which direct an incoming optical signal through a wavelength converter, instead of coupling the signal directly to an output port. Figure 11 shows an alternative router structure. This splits the router into two NxN wavelength multiplexers. Wavelength converters are positioned between the two multiplexers. The wavelength converters may be all-optical devices, or may comprise tuneable receiver/transmitter pairs. With this structure, there is no need for additional dummy ports. This reduces the number of wavelength channels required, and eases device fabrication.

Figure 12 shows an example of the distribution of wavelength channels between different routers in networks such as those described above. Connections from one node only are shown, for ease of illustration. In this example:

N=23 nodes, L=16 wavelengths/fibre

C (capacity) =10 Tbit/s, B (bit rate)=2.5 Gbit/s

Every node must send N-1 =22 wavelengths to each router

C/(N(N-1)B) = 7.905 wavelengths between node pairs, hence r=8 working outers

C/NB = 173.91 = 174 wavelength channels from each node

C/NBL = 10.87 = 11 fibres from each node

In this example, therefore, 7 out of 11 fibres need wavelength channels to be coupled to/from the next router (upstream and downstream)

As shown in Figure 12, two fibres, each capable of carrying 16 channels, extend from a node to working router number 1. Since the node can take 22 channels, 10 channels are left. A tap from one of the two fibres, in a region which is closer to the router than to the node, is connected to inputs of another working router, in this case the adjacent router no. 2. The 10 wavelengths from the tap together with 12 wavelengths from the next fibre fill working router number 2, leaving 4 channels from that next fibre to be carried on, via another tap, to working router number 3 and so on.

Figure 13A shows the use of a wavelength multiplexer at the tap adjacent to router 1 to couple 10 wavelength channels, that is channels 7 to 16, to working router 2. Figure 13B shows the equivalent arrangement at the tap adjacent to working router 2.

CLAIMS

1. An optical communications system comprising:

a) a network having a star topology;

b) a plurality of nodes which are located at the periphery of the network, each node including:

a plurality of wavelength division multiplexing terminals, each wavelength division multiplexing terminal being arranged to communicate optical wavelength division multiplexing signals, via the network, with another terminal in a selected other one of the plurality of nodes; and

c) a plurality of routers at the hub of the network, each one of the routers comprising a wavelength division multiplexer having a capacity which is less than the capacity of the network as a whole, and the routers in total having a capacity which is greater than that of the network as a whole, and each of the routers being connected in parallel to a plurality of the said nodes.

2. A system according to any claim 1, in which the routers are passive routers.

3. An optical communications system comprising:

a) a network having a star topology;

b) a plurality of nodes which are located at the periphery of the network, and which are arranged to communicate optical signals with other nodes via the hub of the network ; and

c) a plurality of routers at the hub of the network, each one of the routers having a capacity which is less than the capacity of the network as a whole, and the routers in total having a capacity which is greater than that of the network as a whole, and each of the routers being connected in parallel to a plurality of the said nodes.

4. A system according to any one of the preceding claims, further comprising an optical switch which is connected to the network and which is operable to select alternative paths for traffic between one node and another node.

5. A system according to claim 4, further comprising a controller which is connected to the optical switch and which is arranged automatically to select one of the alternative paths in response to the detection of a fault condition in another of the alternative paths.

6. A system according to any one of the preceding claims, in which the said nodes are trunk nodes in a telecommunications network, each of the said nodes being arranged to transmit and receive traffic on a plurality of access circuits and to switch the said traffic to selected other nodes.

7. A system according to any one of the preceding claims, in which the plurality of routers include a working router which is arranged to carry working traffic only and standby routers which is arranged to carry protection traffic only.

8. A system according to any one of the preceding claims, in which different ones of the said plurality of routers are located at different sites.

9. A system according to any one of the preceding claims further comprising:

peripheral transmission paths directly connecting different ones of the plurality of nodes.

10. A system according to claim 9 in which the peripheral transmission paths are configured as a ring.

11. A system according to claim 9 or 10, in which the network is arranged, in the event of a network failure, to divert traffic from a direct connection between a node and the hub of the network to an indirect connection, which indirect connection passes via a peripheral transmission path and another node to the hub.

12. A system according to any one of claims 9 to 11, in which a node is arranged to direct part only of the working traffic from the node directly to the hub and is

arranged to direct other working traffic indirectly to the hub via a peripheral transmission path and another node.

13. A system according to any one of the preceding claims, in which a standby optical transmission path is connected to a working optical transmission path at a region of a respective working optical transmission path which lies between a respective node and the hub and which is closer to the hub than to the respective node.

14. A system according to claim 13, in which the standby optical transmission path comprises an optical bus which is connected to a plurality of the working optical transmission paths and to a standby router.

15. A method of operating an optical communications system comprising a network having a star topology, a plurality of nodes located at the periphery of the network, and a plurality of routers connected to the hub of the network, the method comprising:

a) at the nodes, modulating signals onto different wavelength division multiplexing channels carried by optical signals at different respective wavelengths;

b) outputting some optical signals from a node onto one branch of the network which is connected to one of the plurality of routers;

c) outputting other optical signals from the said node onto another branch of the network which is connected to another one of the plurality of the routers; and

d) routing wavelength division multiplexing channels received by the plurality of routers to different destination nodes depending on the wavelength of a respective channel.

16. A method according to claim 15, further comprising switching a wavelength division multiplexing channel which links an originating node and a destination node from a first path via one of the plurality of routers to an alternative path via another one of the routers in the event of a component failure in the said first path.

17. A method of operating an optical communications system comprising a network having a star topology, a plurality of nodes located at the periphery of the network, and a plurality of routers connected to the hub of the network, the method comprising:

a) at the nodes, outputting optical signals directed to different destination nodes;

b) outputting some of the optical signals from a node onto one branch of the network which is connected to one of the plurality of routers;

c) outputting others of the optical signals from the said node onto another branch of the network which is connected to another one of the plurality of the routers; and

d) at the hub routing signals received at the plurality of routers to different destination nodes .

18. A method according to any one of claims 15 to 17, further comprising switching optical signals from one of the said branches to another of the said branches in response to a fault condition in the optical communications system.

19. A method according to any one of claims 15 to 18, including directing working traffic only to some of the plurality routers, and directing protection traffic only to others of the plurality of routers.

20. A method according to any one of claims 15 to 19, including a step of diverting traffic from a direct connection between a node and the hub of the network to an indirect connection between a node and a hub, which indirect connection passes via a peripheral transmission path which directly connects two or more of the said nodes.

21. A method according to claim 20, in which the step of diverting traffic is carried out in response to a fault condition in the communications system.

22 A method according to any one of claims 15 to 21, including directing some of the optical signals from a node to the hub of the network on an indirect connection, which indirect connection passes via a peripheral transmission path which directly connects two or more of the said nodes.

23. A method according to any one of claims 15 to 22, including directing standby traffic to the hub via a standby optical transmission path which is connected to a working optical transmission path at a region of a respective working optical transmission path which lies between a respective node and the hub and which is closer to the hub than to the respective node.

24. A method according to claim 23, in which the standby traffic is directed via an optical bus which is connected to a plurality of the working optical transmission paths and to a standby router.

25. An optical communications system comprising:

a) a network having a star topology;

b) a plurality of nodes which are located at the periphery of the network, each node including:

a plurality of wavelength division multiplexing terminals, each wavelength division multiplexing terminal being arranged to communicate optical wavelength division multiplexing signals, via the network, with another terminal in a selected other one of the plurality of nodes; and

c) a plurality of wavelength division multiplexing routers connected to the hub of the network, each one of the wavelength division multiplexing routers having a capacity which is less than the capacity of the network as a whole, and the wavelength division multiplexing routers in total having a capacity which is greater than that of the network as a whole, and each of the routers being connected in parallel to a plurality of the said nodes.

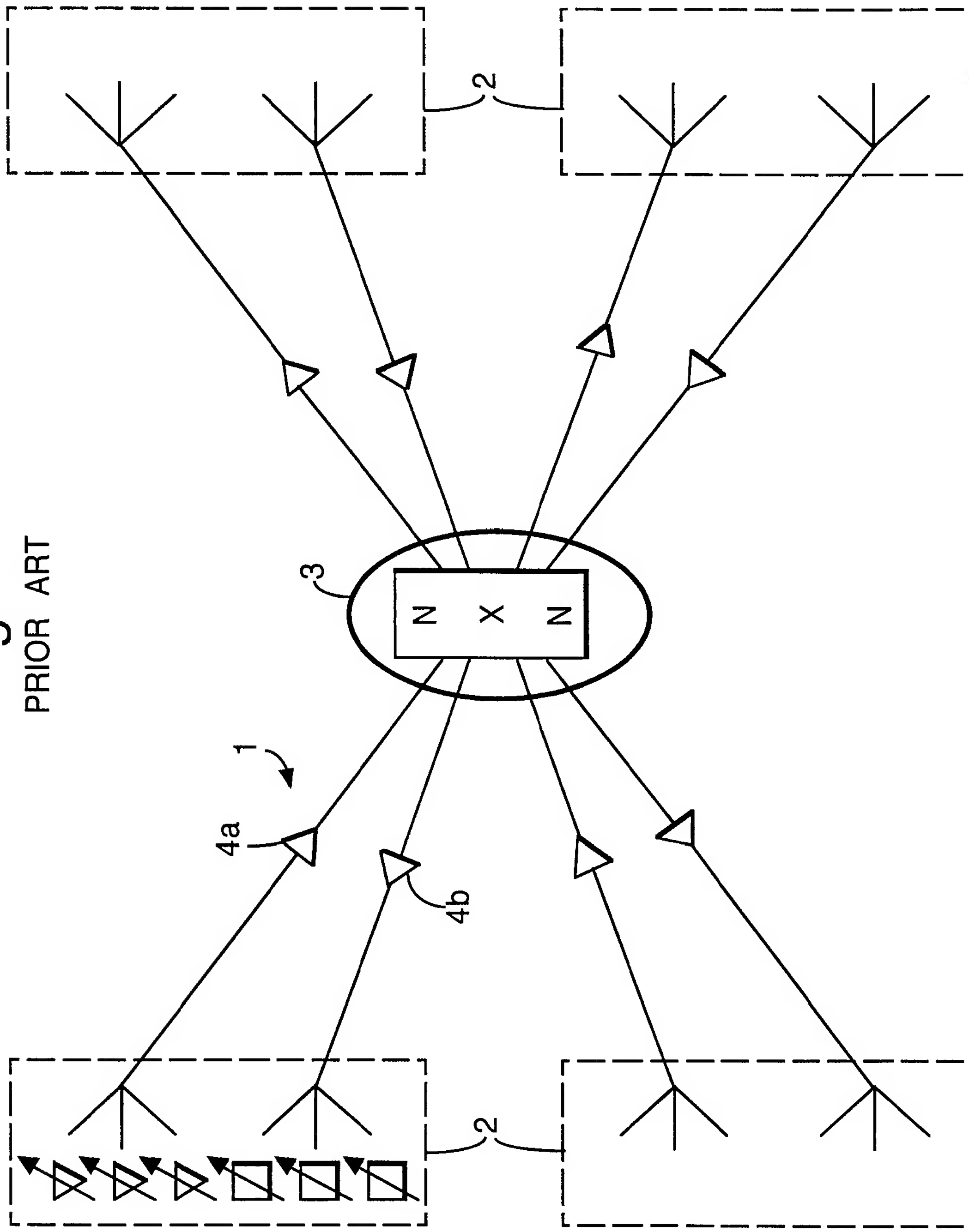


Fig.1.
PRIOR ART

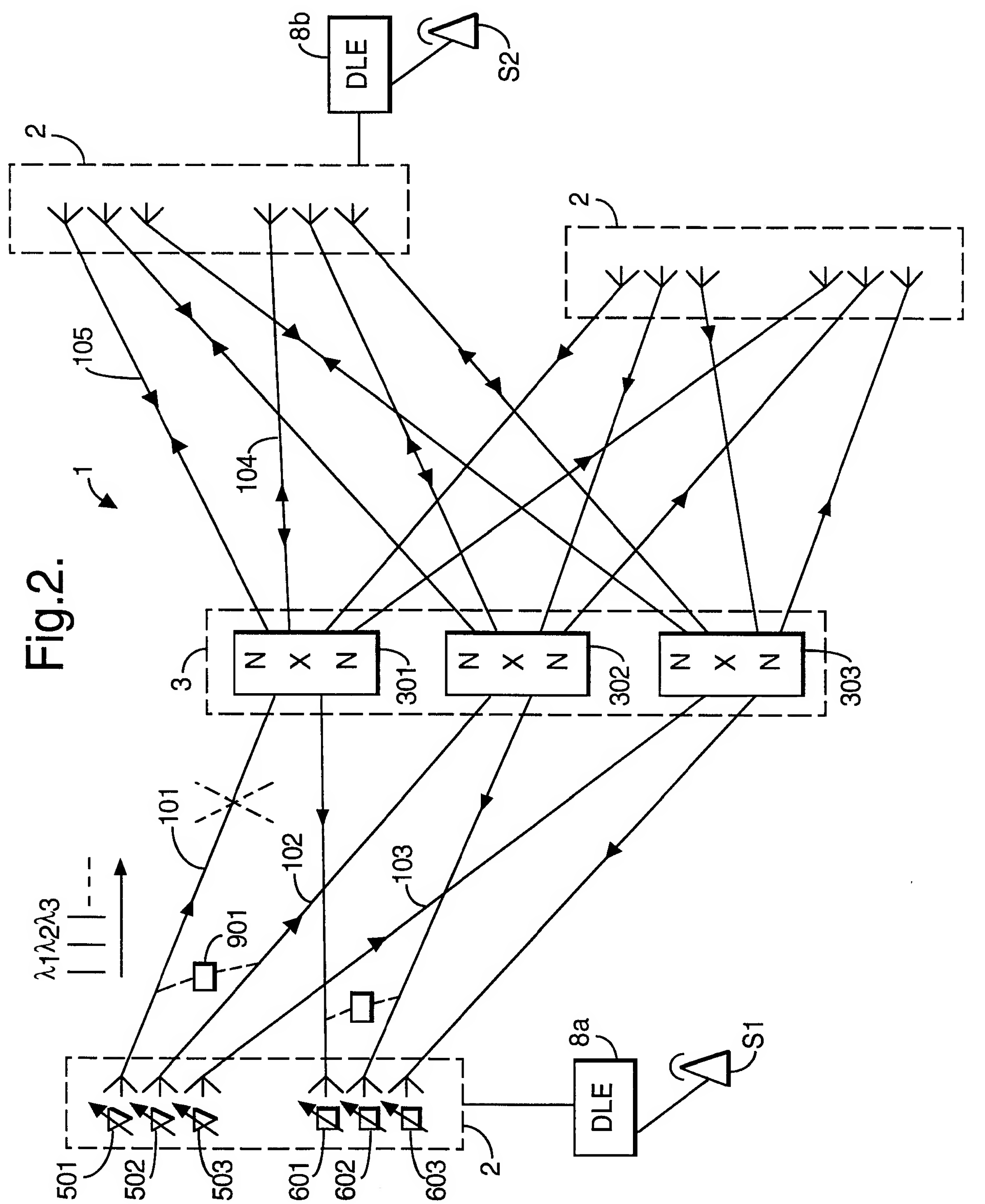

8b
DLE
S2
2
105
104
1
3
N X N
301
302
303
101
102
103
901
λ1λ2λ3
8a
DLE
S1
501
502
503
601
602
603

Fig.2.

Fig.3.

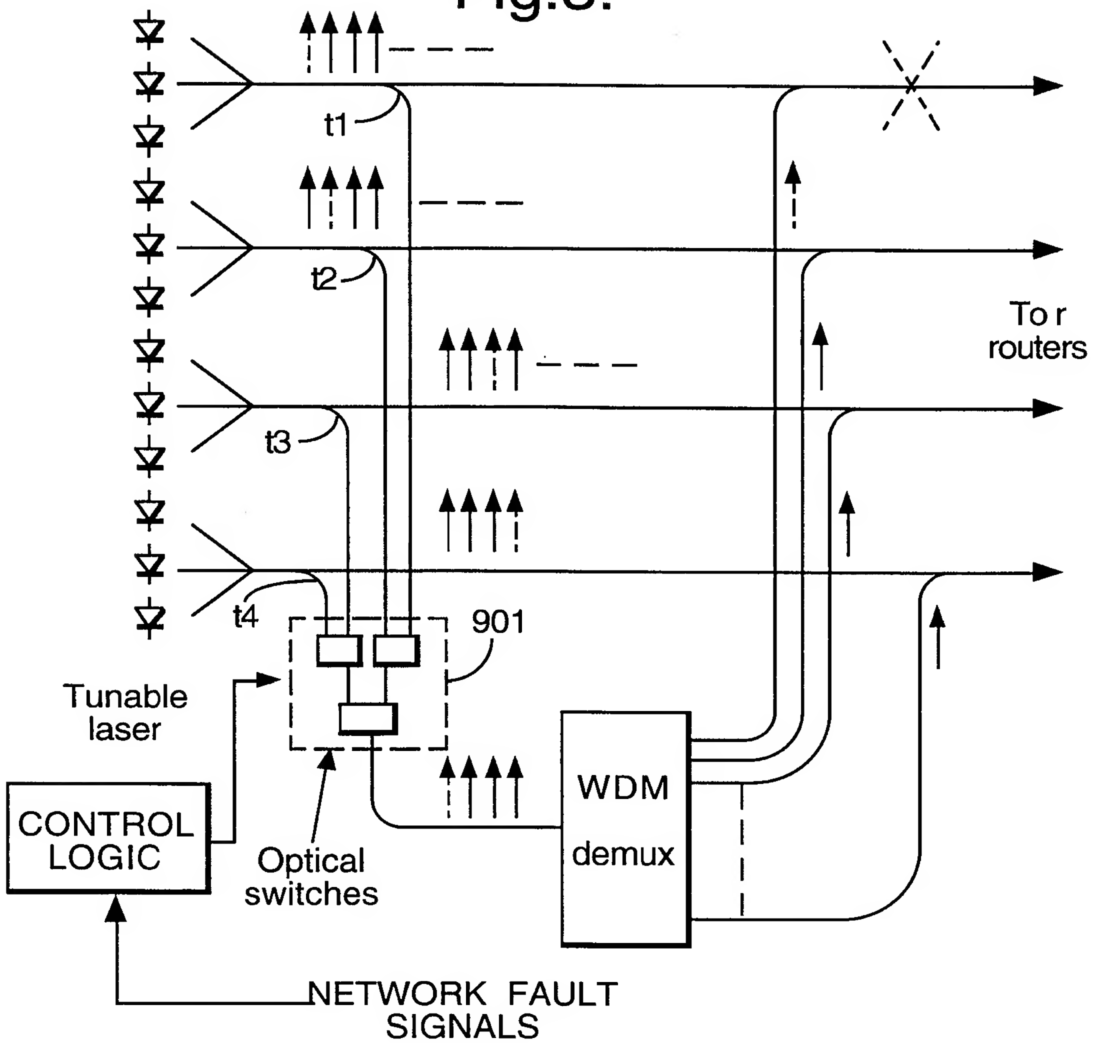

t1
t2
t3
t4
901
To r
routers
Tunable
laser
CONTROL
LOGIC
Optical
switches
WDM
demux
NETWORK FAULT
SIGNALS

Fig.4.

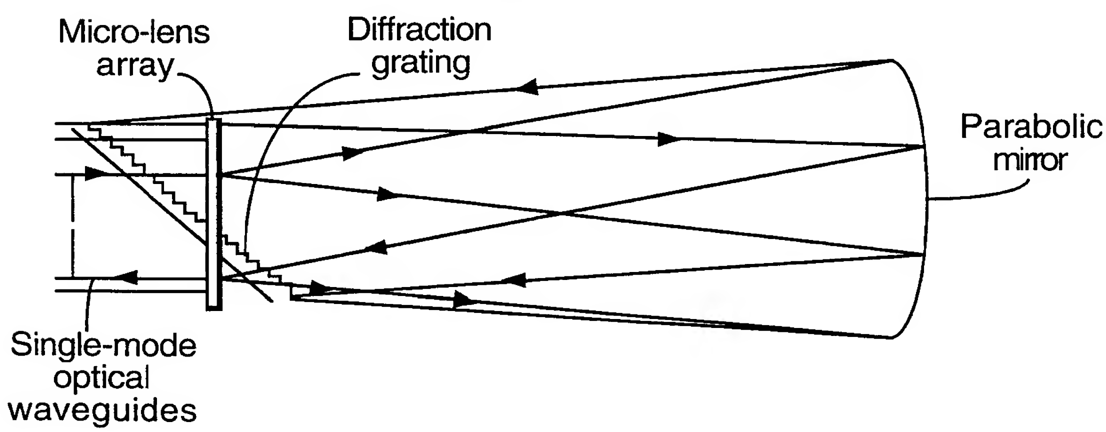

Micro-lens
array
Diffraction
grating
Parabolic
mirror
Single-mode
optical
waveguides

Fig.5.

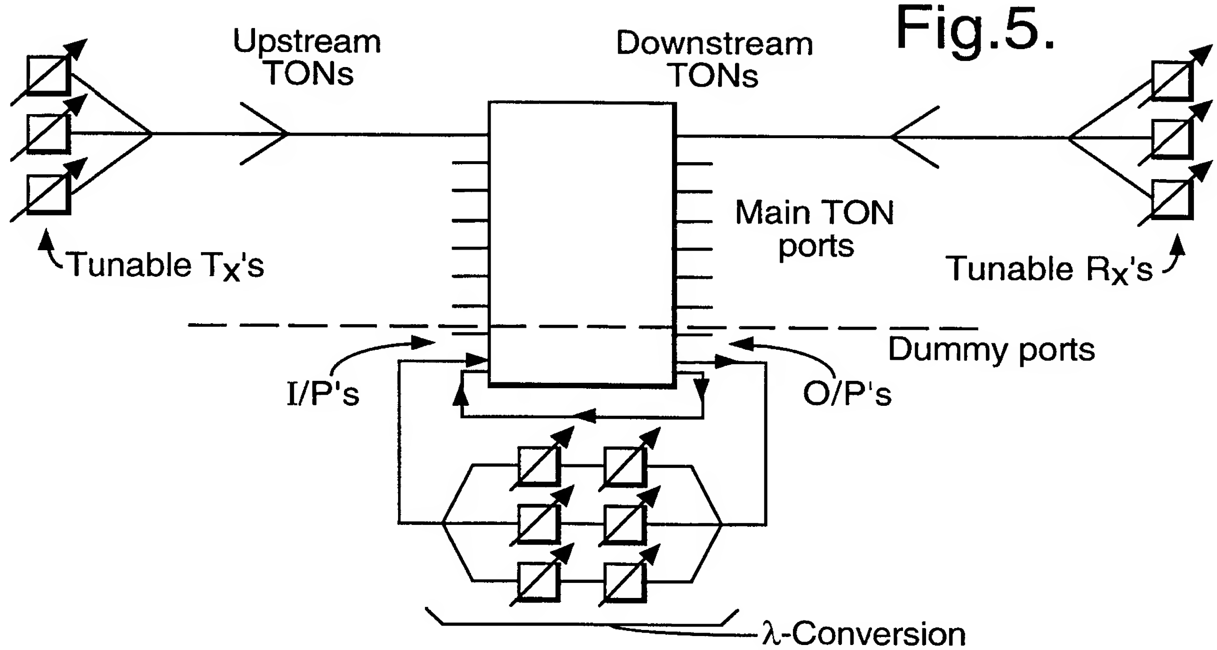

Upstream
TONs
Downstream
TONs
Tunable Tx's
Main TON
ports
Tunable Rx's
Dummy ports
I/P's
O/P's
λ-Conversion

Fig.9.

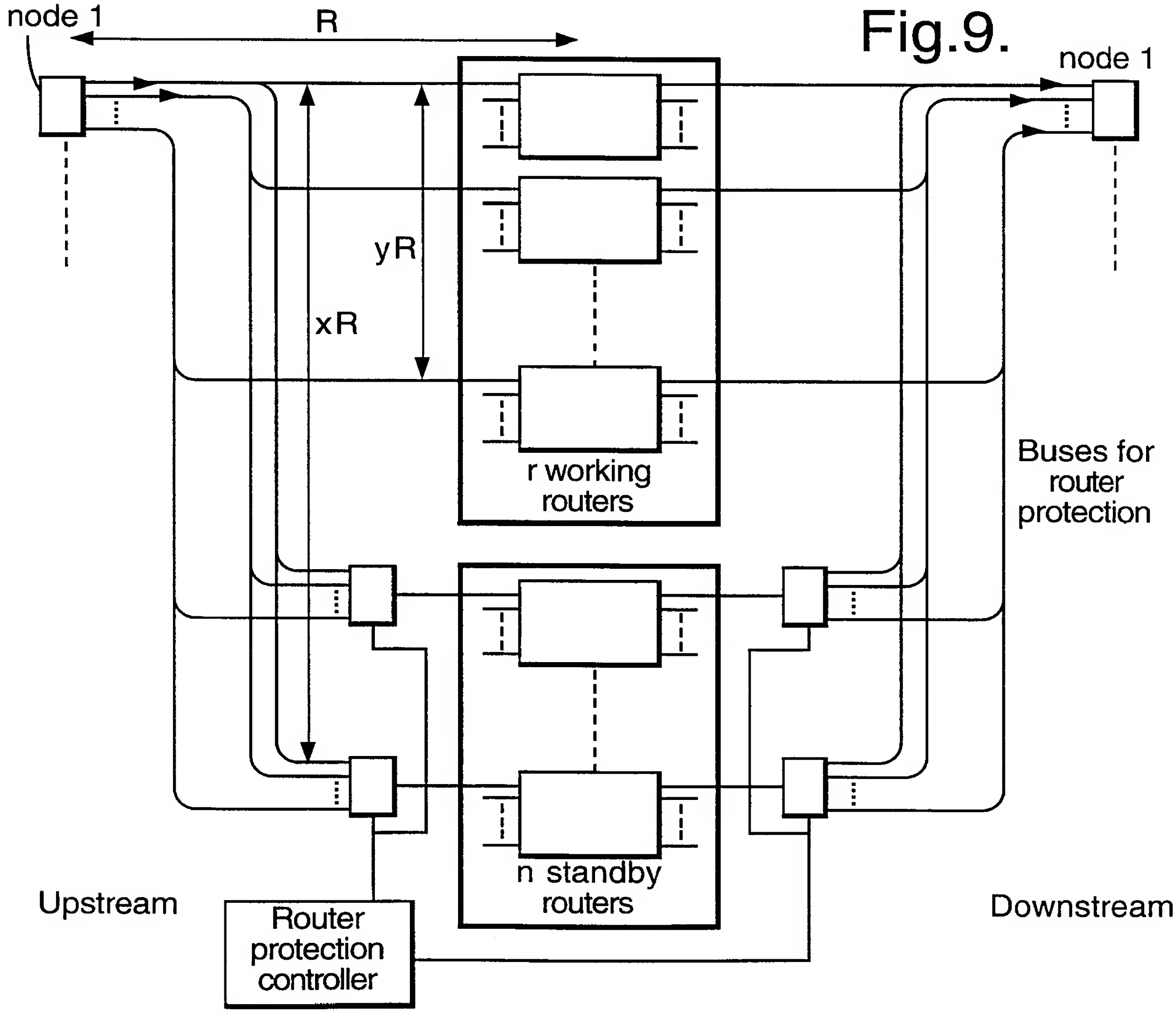

node 1
R
node 1
yR
xR
r working
routers
Buses for
router
protection
n standby
routers
Upstream
Downstream
Router
protection
controller

Fig.6.

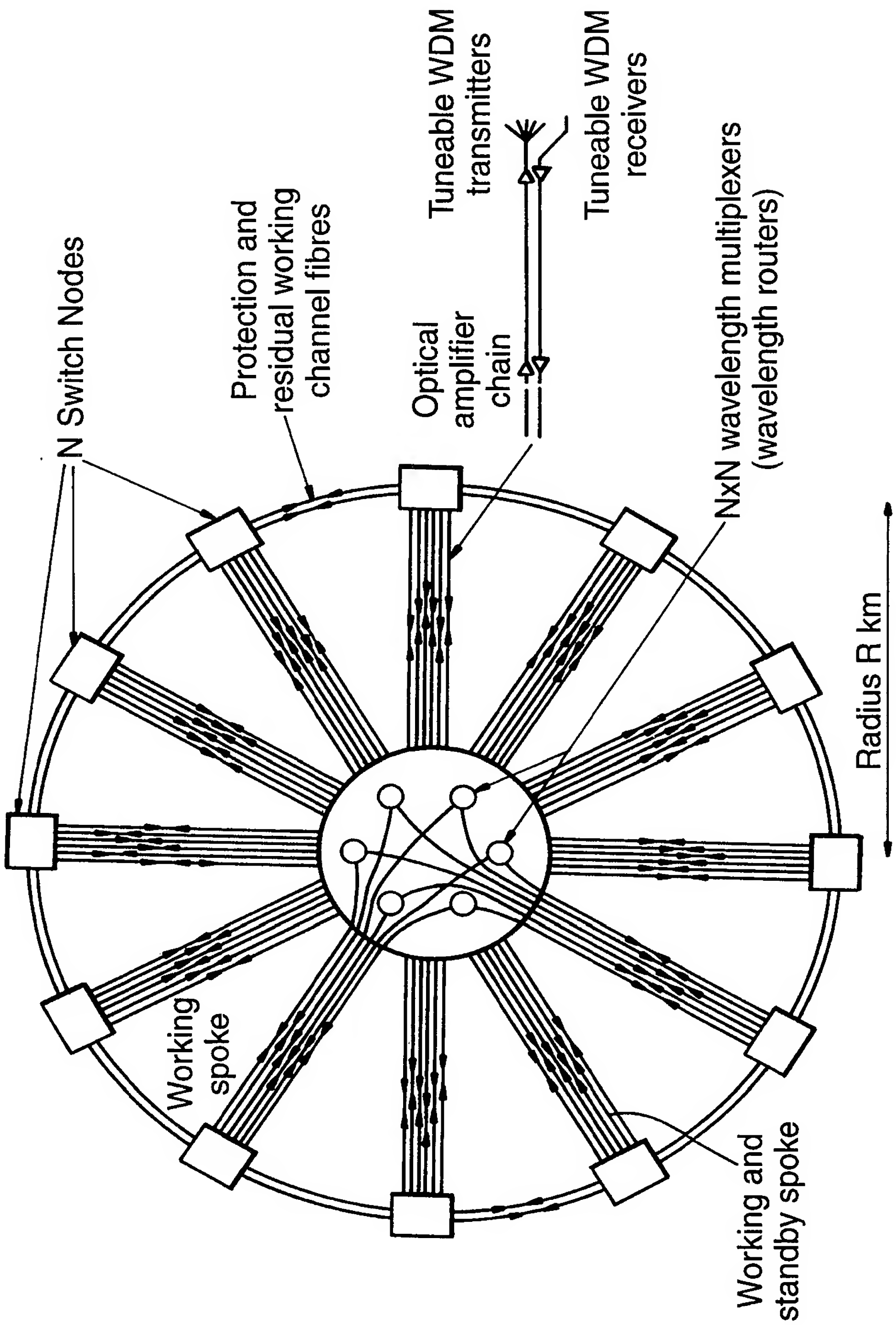

N Switch Nodes
Protection and residual working channel fibres
Optical amplifier chain
Tuneable WDM transmitters
Tuneable WDM receivers
NxN wavelength multiplexers (wavelength routers)
Radius R km
Working spoke
Working and standby spoke

Fig.7.

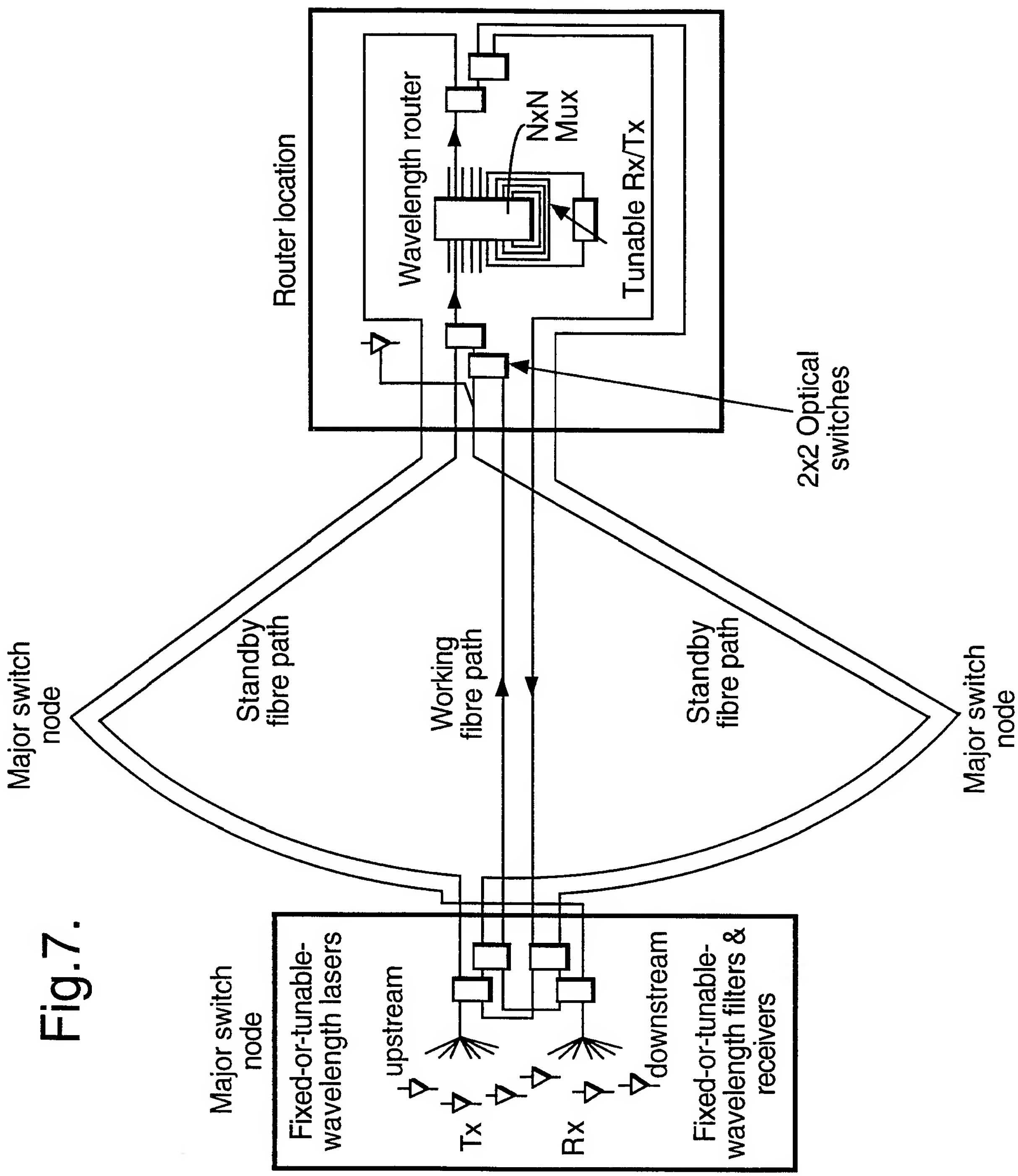

Router location
Wavelength router
NxN Mux
Tunable Rx/Tx
2x2 Optical switches
Major switch node
Standby fibre path
Working fibre path
Standby fibre path
Major switch node
Major switch node
Fixed-or-tunable-wavelength lasers
upstream
Tx
Rx
downstream
Fixed-or-tunable-wavelength filters & receivers

Fig.8.

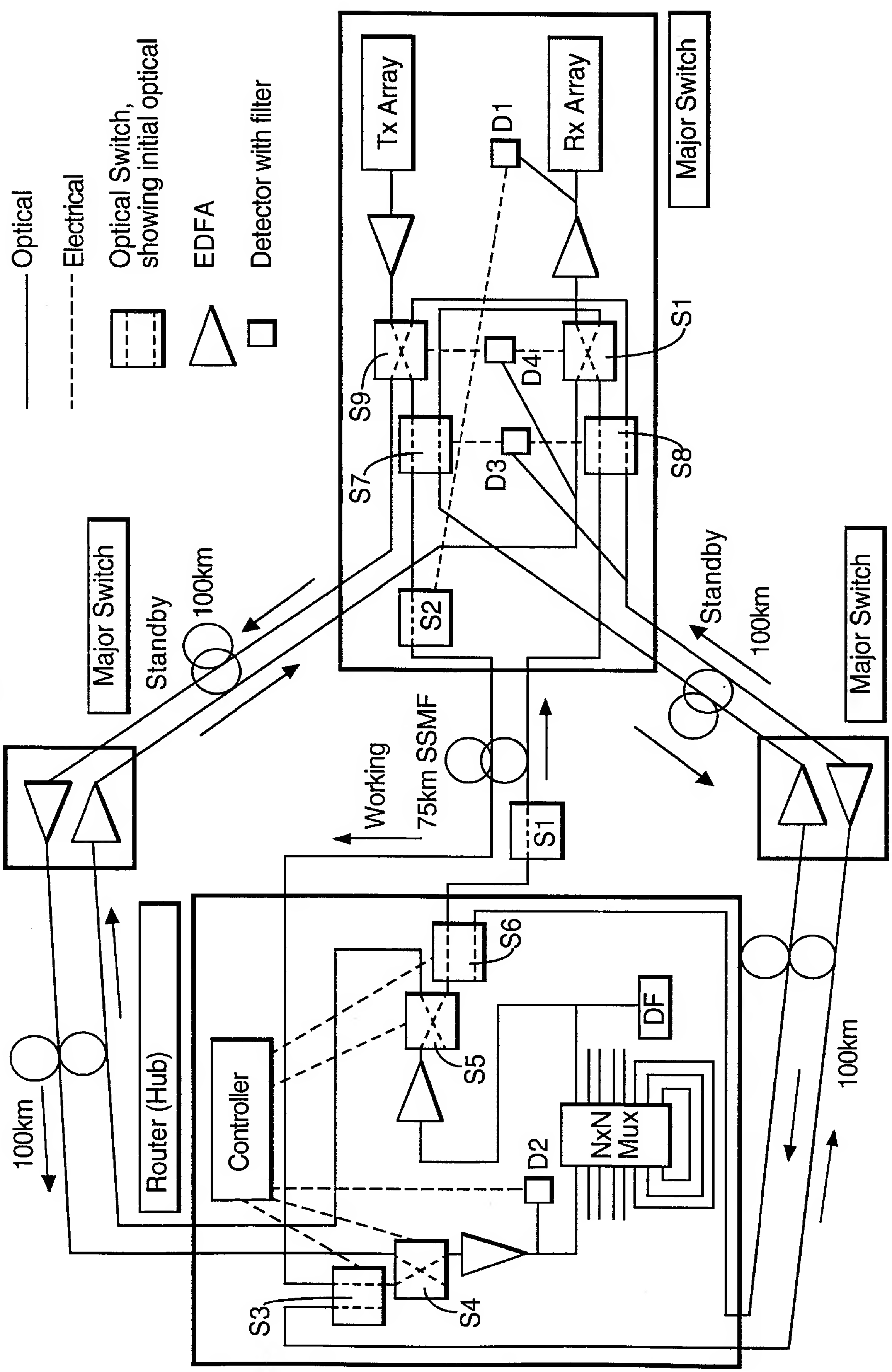

Optical
Electrical
Optical Switch, showing initial optical
EDFA
Detector with filter
Tx Array
Rx Array
D1
Major Switch
S9
S1
D4
S7
D3
S8
S2
Major Switch
Standby
100km
Standby
100km
Major Switch
Working
75km SSMF
S1
Router (Hub)
100km
Controller
S6
S5
DF
NxN Mux
D2
S3
S4
100km

Fig.10.

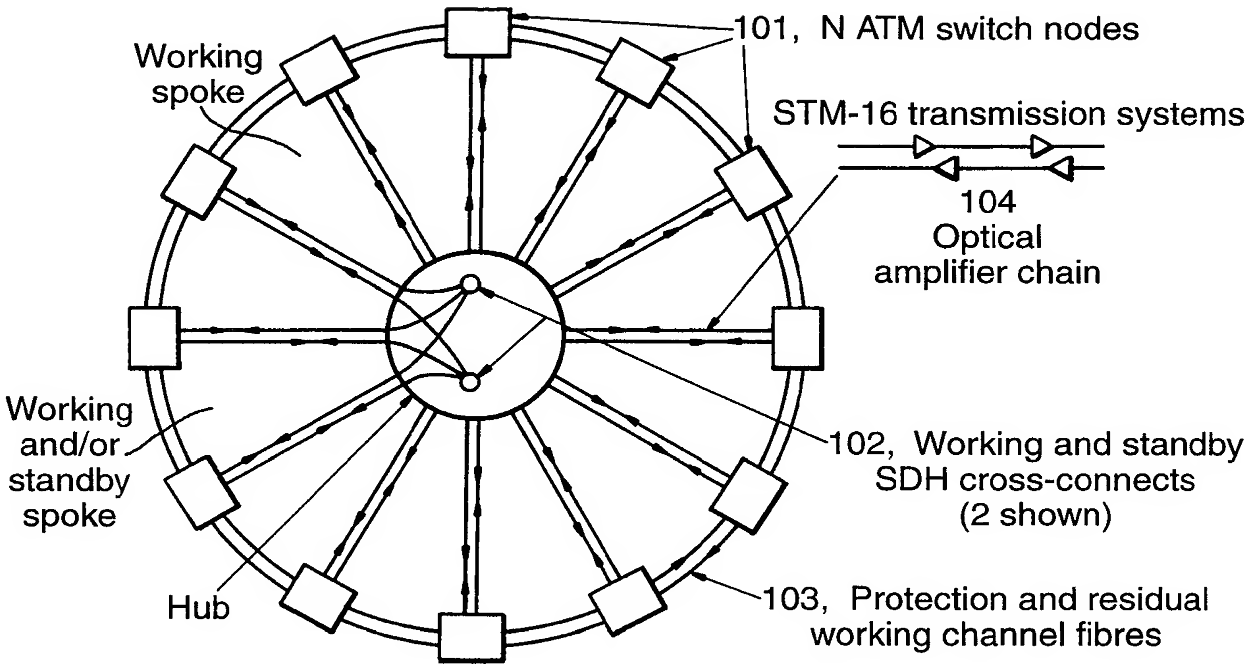
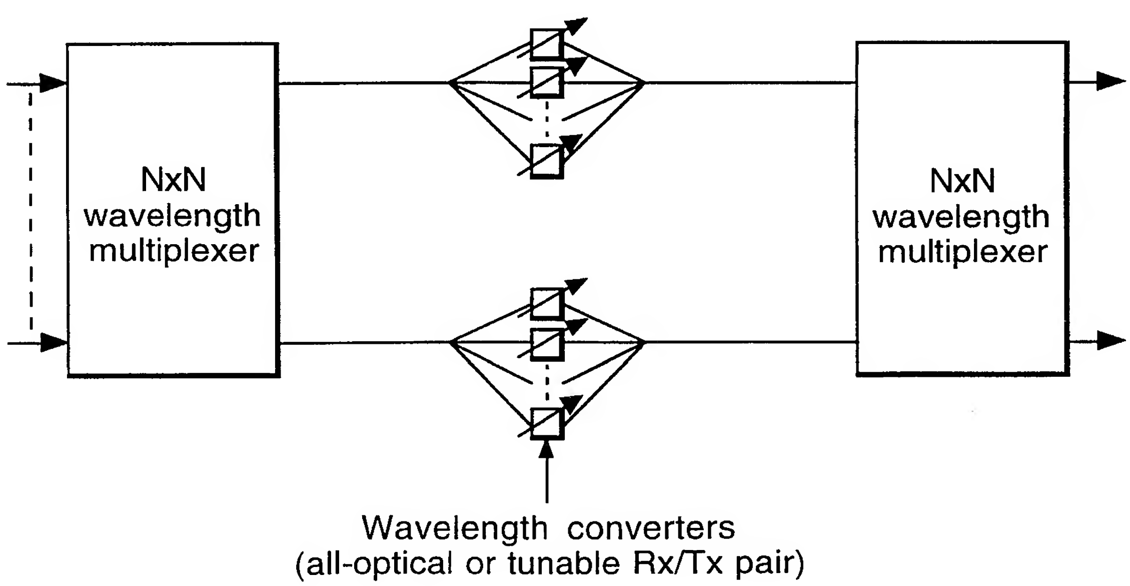

101, N ATM switch nodes
Working spoke
STM-16 transmission systems
104
Optical amplifier chain
Working and/or standby spoke
102, Working and standby SDH cross-connects (2 shown)
Hub
103, Protection and residual working channel fibres

Fig.11.


NxN wavelength multiplexer
NxN wavelength multiplexer
Wavelength converters
(all-optical or tunable Rx/Tx pair)

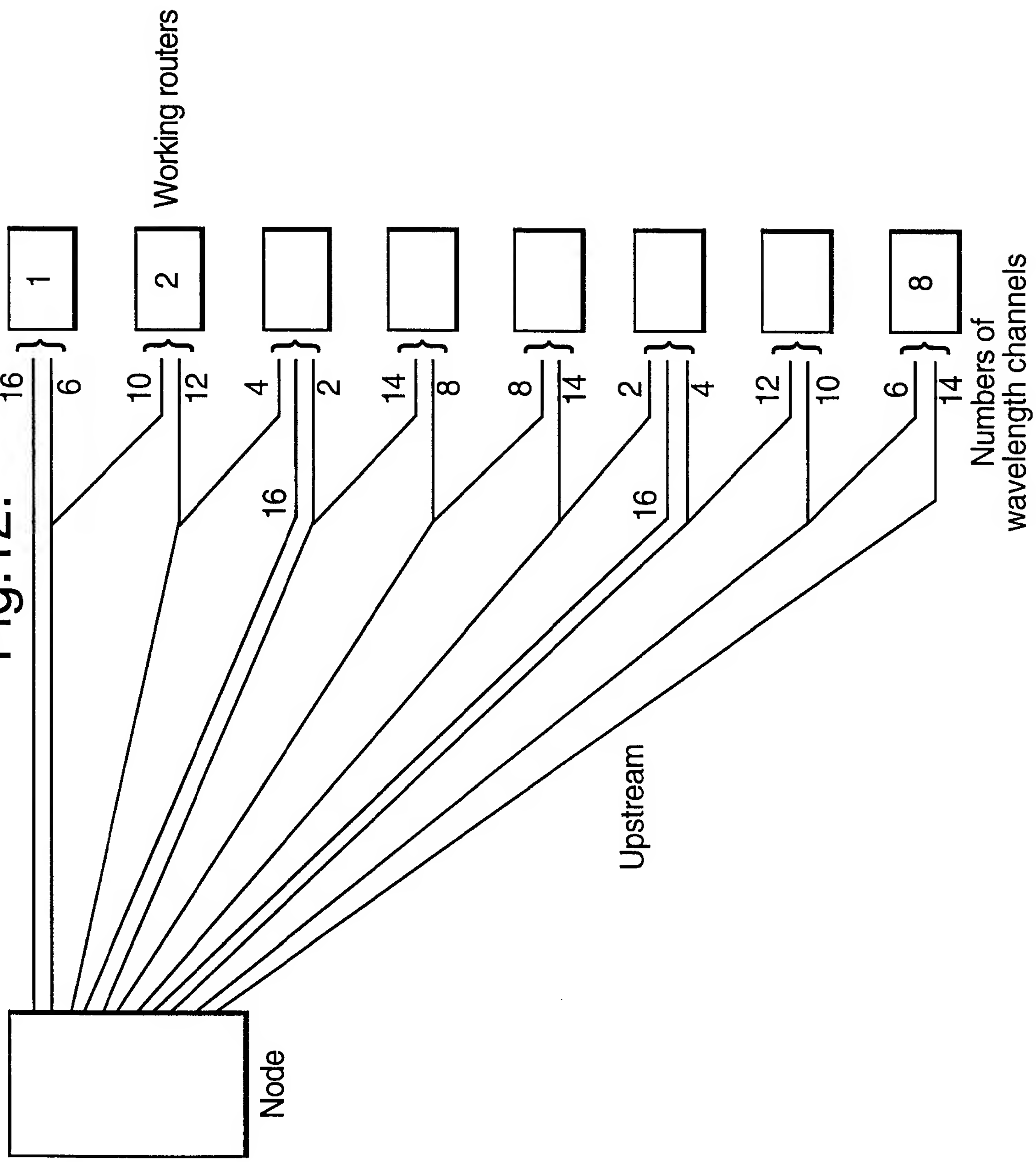

Working routers
1
2
8
16
6
10
12
4
2
14
8
8
14
2
4
12
10
6
14
16
16
Numbers of wavelength channels
Upstream
Node

Fig.12.

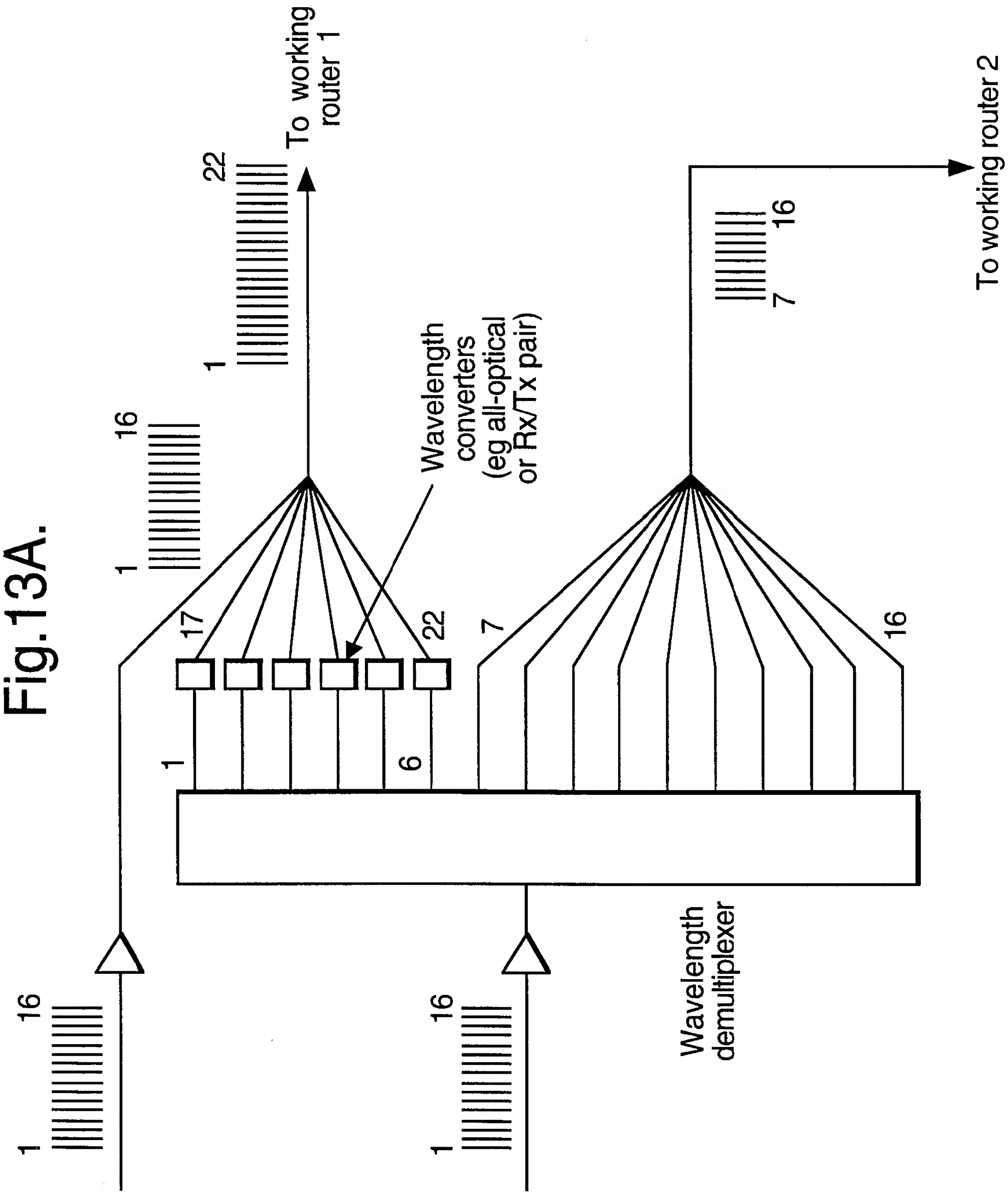

1
16
1
16
1
16
1
22
To working router 1
17
22
1
6
7
16
Wavelength converters (eg all-optical or Rx/Tx pair)
7
16
To working router 2
Wavelength demultiplexer

Fig.13A.

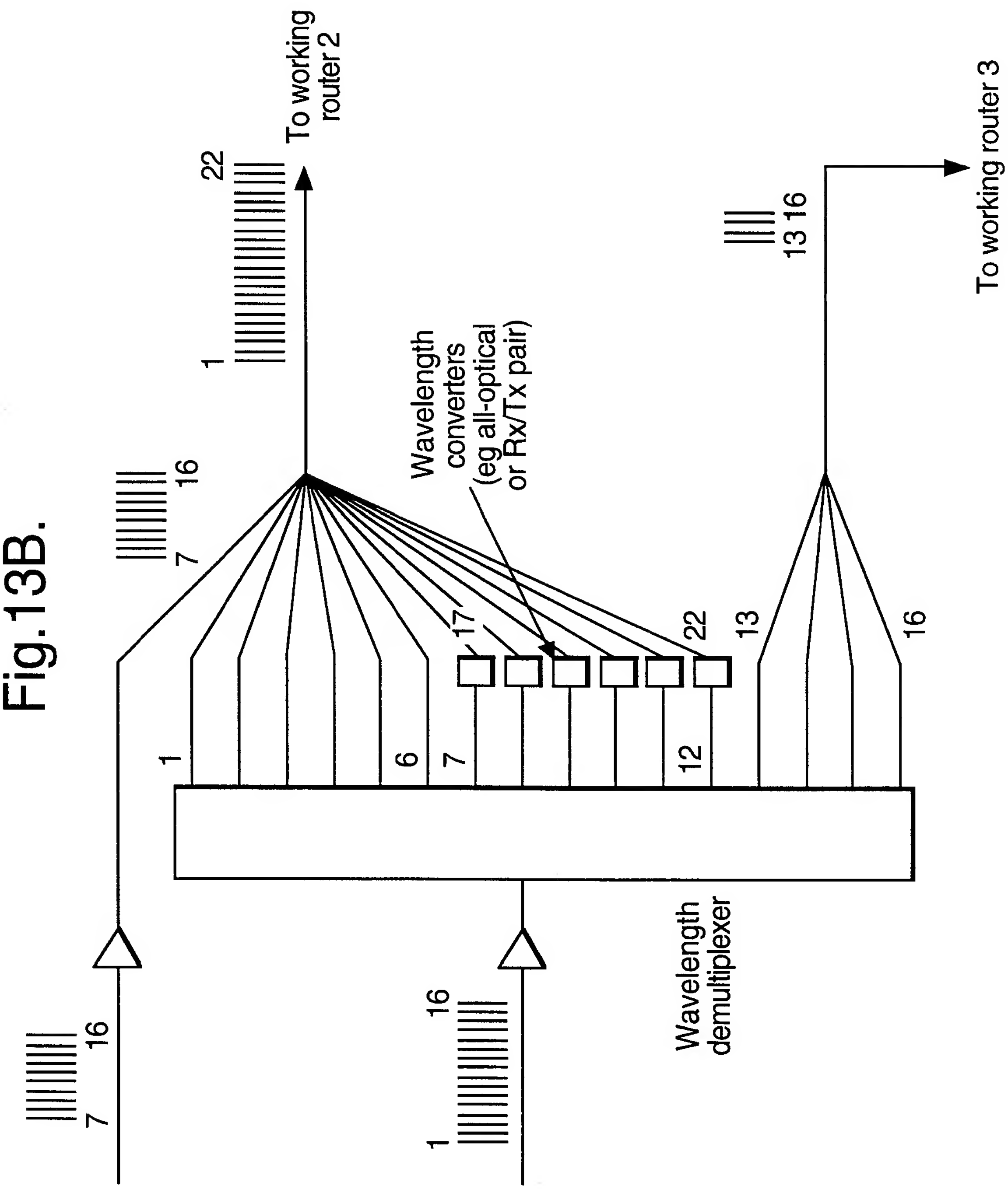

To working router 2
1
22
7
16
Wavelength converters (eg all-optical or Rx/Tx pair)
17
22
13
16
13 16
To working router 3
1
6
7
12
7
16
1
16
Wavelength demultiplexer

Fig.13B.

INTERNATIONAL SEARCH REPORT

Int .ional Application No
PCT/GB 98/00169

A. CLASSIFICATION OF SUBJECT MATTER
IPC 6 H04B10/207 H04J14/02 H04Q11/00

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 6 H04B H04J H04Q G02B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	SHARONY J ET AL: "THE WAVELENGTH DILATION CONCEPT IMPLEMENTATION AND SYSTEM CONSIDERATIONS" DISCOVERING A NEW WORLD OF COMMUNICATIONS, CHICAGO, JUNE 14 - 18, 1992, vol. VOL. 2, no. -, 14 June 1992, INSTITUTE OF ELECTRICAL AND ELECTRONICS ENGINEERS, pages 829-836, XP000326793	1,3,25
A	see page 832, left-hand column, last line - page 833, left-hand column, paragraph 1; figure 9	15,17

	-/--	

[X] Further documents are listed in the continuation of box C.

[X] Patent family members are listed in annex.

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"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed

"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
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"&" document member of the same patent family

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Date of the actual completion of the international search	Date of mailing of the international search report
16 April 1998	28/04/1998

Name and mailing address of the ISA	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Tx. 31 651 epo nl, Fax: (+31-70) 340-3016	Pieper, T

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INTERNATIONAL SEARCH REPORT

International Application No
PCT/GB 98/00169

C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category °	Citation of document, with indication,where appropriate, of the relevant passages	Relevant to claim No.
X	OBARA H ET AL: "SCALABLE TWO-STAGE WDM CROSSCONNECT ARCHITECTURE" ELECTRONICS LETTERS, vol. 32, no. 1, 4 January 1996, page 57/58 XP000553379 see abstract see page 57, left-hand column, line 1 - line 23	15,17
A	see page 57, left-hand column, line 56 - right-hand column, line 39; figure 2A ---	1-3,24
A	US 5 043 975 A (MCMAHON DONALD H) 27 August 1991 see column 2, line 43 - line 62 see column 3, line 21 - line 52 see column 8, line 11 - line 25 see column 8, line 48 - line 55 see figures 1,2 ---	1-6,9, 11,13, 15-18, 23,25
A	HILL G R: "A WAVELENGTH ROUTING APPROACH TO OPTICAL COMMUNICATIONS NETWORKS" NETWORKS: EVOLUTION OR REVOLUTION?, NEW ORLEANS, MAR. 27 - 31, 1988, no. CONF. 7, 27 March 1988, INSTITUTE OF ELECTRICAL AND ELECTRONICS ENGINEERS, pages 354-361, XP000044787 see page 355, left-hand column, line 3 - line 40; figures 1-4,6 ---	1-6, 15-18,25
A	EP 0 215 711 A (INT STANDARD ELECTRIC CORP) 25 March 1987 see page 1, line 13 - line 21 see page 1, line 28 - line 30 see page 2, line 9 - line 20 see page 3, line 31 - page 4, line 2 see page 4, line 6 - page 5, line 1 ---	1,3,7,8, 13,15, 17,19, 23,25
A	PATENT ABSTRACTS OF JAPAN vol. 008, no. 013 (E-222), 20 January 1984 & JP 58 177041 A (NIPPON DENKI KK), 17 October 1983, see abstract -----	1-4, 9-11, 15-18, 20-22,25

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INTERNATIONAL SEARCH REPORT

Information on patent family members

Inte onal Application No
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		US 4775210 A	04-10-88